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DSTO-TN-0022

Short Range Lateral Variability of Seabed Properties (With Some Notes on Larger Scale Features) Near Port Hedland, W.A.

P.J. Mulhearn

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P.J. Mulhearn

Maritime Operations Division
Aeronautical and Maritime Research Laboratory

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ABSTRACT

The spatial variability of seabed sediment properties over short ranges is investigated, and it is found that, at least for sands, sediment grain-size varies within a factor of $\sqrt{2}$ over distances of order 100 m. Evidence is then presented that this sediment variability, found off Port Hedland, is similar to that at many other locations around the world. Hence for acoustic backscatter and mine burial models the conventional categories: very coarse, coarse, medium, fine and very fine, for sands are as precise as it is practical to be. This implies that survey methods, with, for example, acoustic sea floor classification systems, need only provide sediment grain size to this level of accuracy. It also means that, for mine-counter measures purposes, conventional survey methods can be relatively simple, and that many existing data bases are quite adequate.

From underwater video footage it is clear that many important seabed features, such as shell beds, branching corals and sea-weed clumps, can easily be overlooked in sea floor surveys, with either grabs or corers alone, and that this, at times, would lead to misleading conclusions concerning environmental factors relevant to mine warfare operations.

A number of interesting seabed features have been observed near Port Hedland using a sub-bottom profiler and diver-operated underwater video cameras. Because so little is known in this area, it was thought these observations were worth recording, as an appendix to this report. In particular video-camera observations of some of the long, linear, underwater ridges off Port Hedland established them to be rocky reefs, rather than sand bars, as was previously thought. This changes previous perceptions of likely mine burial mechanisms off a number of Northwest Shelf ports.

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Short Range Lateral Variability of Seabed Properties (with some notes on larger scale features) near Port Hedland, W.A.

Executive Summary

Evidence is presented to show that, due to the natural variability of sea floor sediment properties, there is no point, for acoustic backscatter and mine burial models, in attempting to specify sediment grain size for sand more precisely than as given by the conventional categories: very coarse, coarse, medium, fine and very fine. This implies that survey methods, with, for example, acoustic sea floor classification systems, need only provide sediment grain size to this level of accuracy. It also means that, for mine-counter measures purposes, conventional survey methods can be relatively simple, and that many existing data bases are quite adequate.

From underwater video footage it is clear that many important seabed features, such as shell beds, branching corals and sea-weed clumps, can easily be overlooked in sea floor surveys, with either grabs or corers alone, and that this, at times, would lead to misleading conclusions concerning environmental factors relevant to mine warfare operations.

A number of interesting seabed features have been observed near Port Hedland using a sub-bottom profiler and diver-operated underwater video cameras. Because so little is known in this area, it was thought these observations were worth recording, as an appendix to this report. In particular video-camera observations of some of the long, linear, underwater ridges off Port Hedland established them to be rocky reefs, rather than sand bars, as was previously thought. This changes previous perceptions of likely mine burial mechanisms off Port Hedland and off a number of other Northwest Shelf ports, such as Broome and Port Walcott.

Contents

1. Introduction

The nature of the sea bed has a considerable influence on mine-counter measure (MCM) operations, governing the level of sea floor acoustic back-scatter and the extent to which ground mines will bury. A range of models have been developed for estimating these factors, and they all require sea floor sediment properties as inputs. The reliability of the models is, of course, dependent on the accuracy of the input data. The accuracy of the inputs depends on, among other factors, (1) the extent to which sediment properties vary between sampling points, because sea floor sediment property values are usually obtained from point samples, obtained with grabs or cores, and (2) the degree to which conventional sediment sampling methods convey a realistic picture of sea floor conditions, as far as MCM operations are concerned.

During a research cruise aboard the CSIRO's FRV Southern Surveyor in the approaches to Port Hedland in October 1993, closely spaced sediment samples were taken along lines at a number of locations, either by divers or with grabs, while the ship was drifting. Video films were also obtained along various tracks, either by divers or by towing a frame -mounted video camera as the ship drifted. The region investigated off Port Hedland was in the depth range 10 to 20 m, which is 10 to 40 km offshore in this area. From these films many sea floor features could be observed, which would have been unknowable with grab sampling alone. From the sediment samples, sediment property values were measured in the laboratory at Maritime Operations Division, Sydney, and statistics on property variations obtained. Quantitative analyses were not carried out on the video films.

The spatial distribution of sediment properties in the shallow water (10 to 26 m deep) approaches to Port Hedland have been described by Mulhearn and Cerneaz (1994). These sediments consist predominantly of sand and gravelly sand, with some sandy gravel areas, and lesser areas of gravel and of muddy sand. The principle mine burial mechanisms in the area have been discussed by Mulhearn (1994).

2. Experimental Procedures

To examine the spatial variability, over short distances, of sea floor sediment properties, sediment samples were taken at regular intervals either by divers using plastic sediment sample jars (at two locations), or from the ship as it drifted using a Shipek grab (at 6 different locations). Sampling and videoing locations are shown in Figure 1 and listed in Tables 1 to 3. For the divers' samples, a 100 m long line was laid out across the sea floor and samples taken every ten metres. At one location, site C,

three such lines were laid out, radiating in different directions from a frame instrumented with underwater cameras and a current meter[1]. (See Figure 2). Video film was also taken along these three lines while the samples were being obtained. At the other location, site K, only one line was laid out. No overall trend with distance was apparent in sediment properties at either of sites C or K, although there was definite sample to sample variability. For each shipboard traverse, the grab was dropped at approximately 5 min intervals, as the ship drifted, obtaining a total of 10 samples. No overall trend with distance was apparent for sediment properties at only two of the six ship drift stations, sites D and J. Data from the other four sites, which did show a trend with distance were not analysed in detail. The distances covered at sites D and J, as the ship drifted in a reasonably straight line, were 0.48 km and 1.81 km, respectively.

Table 1. Stations with grabs every 5 minutes, ship drifting - 10 grabs each.

Stn	Date	Start Time	Start Position		End Position	
Name		(local)	Latitude(S)	Longitude(E)	Latitude(S)	Longitude(E)
D	7/10/93	17:48	19° 57.18'	118° 29.98'	19° 56.92'	118° 29.94'
J	7/10/93	13:02	20° 09.65'	118° 27.31'	20° 09.65'	118° 28.35'

Table 2. Stations at which divers obtained bottom samples every 10 m.

Stn Name	Date	Time (local)	Latitude (S)	Longitude (E)	Bearing of Line (° M)	Length of line (m)
C	7/10/93	07:30	20° 12.28'	118° 26.48'	240	90
C	8/10/93	14:20	20° 12.28'	118° 26.48'	90	80
C	11/10/93	14:30	20° 12.28'	118° 26.48'	165	70
K	7/10/93	11:45	20° 09.92'	118 ° 31.18'	120	90

Sediment samples were analysed, in the laboratory, for grain density, bulk density, porosity, percentages of gravel, sand and mud, and percentages of very coarse, coarse, medium, fine and very fine sand in the sand fraction. The geological definitions of gravel, sand, mud and the various sand fractions are given in Appendix A. (Note that these are particle size descriptions, not mineralogical ones).

[1] The work for which this frame was used is not discussed herein.

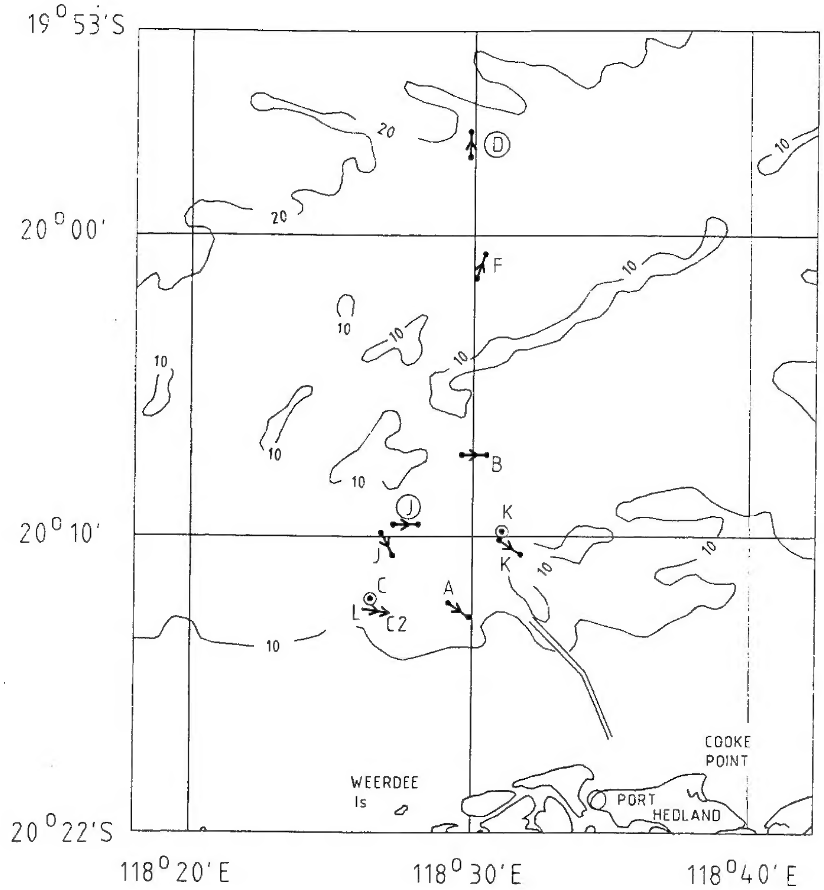

Figure 1. Positions of measurement locations off Port Hedland. Arrows with uncircled letters designate ship drifts with sea floor video camera; arrows with circled letters denote ships drifts on which regular grab samples were obtained; circled dots with an adjacent letter denote positions of diver's traverses on which regular sediment samples were obtained.

The following statistics of the particle size distribution were then calculated for each sample: median and graphic mean size, graphic standard deviation and graphic skewness. The sample to sample variation in these parameters at sites C, K, D and J were then calculated. Particle sizes are normally given in φ-sizes, where $\varphi = -\log(\text{particle diameter in mm})/\log(2)$.

Sediments always contain a range of sizes and graphic mean size, Mz, is defined by:

$$Mz = (\varphi 16 + \varphi 50 + \varphi 84)/3.$$

Other parameters are:

Median grain size = $\varphi 50$,

graphic standard deviation, $\sigma_G = (\varphi 84 - \varphi 16)/2$, and

graphic skewness, $Sk_G = (\varphi 16 + \varphi 84 - 2\varphi 50)/(\varphi 84 - \varphi 16)$,

where φxx is the φ-size at which a particle cumulative size distribution is xx%, i.e. the φ-size for which xx% of the sample has particle sizes larger than φxx. The above definitions are taken from Folk (1980). Sediment analyses for grain density, bulk density, porosity and sediment grain size distributions were carried out as described in Mulhearn and Cerneaz (1994).

Videofilms of the sea floor were also obtained, while the ship drifted on station, using an underwater video camera mounted in a protective frame, to which a length of trailing chain was attached. The frame was lowered till it met the sea floor then raised approximately one metre. The weight distribution on the frame was arranged so that the camera pointed down at approximately 45°, and the trailing chain was designed to drag behind the frame so that the camera pointed forward, as the ship drifted, under the influence of wind and tide. This simple system worked often enough to give much useful footage. On most occasions the ship drifted in a reasonably straight line.

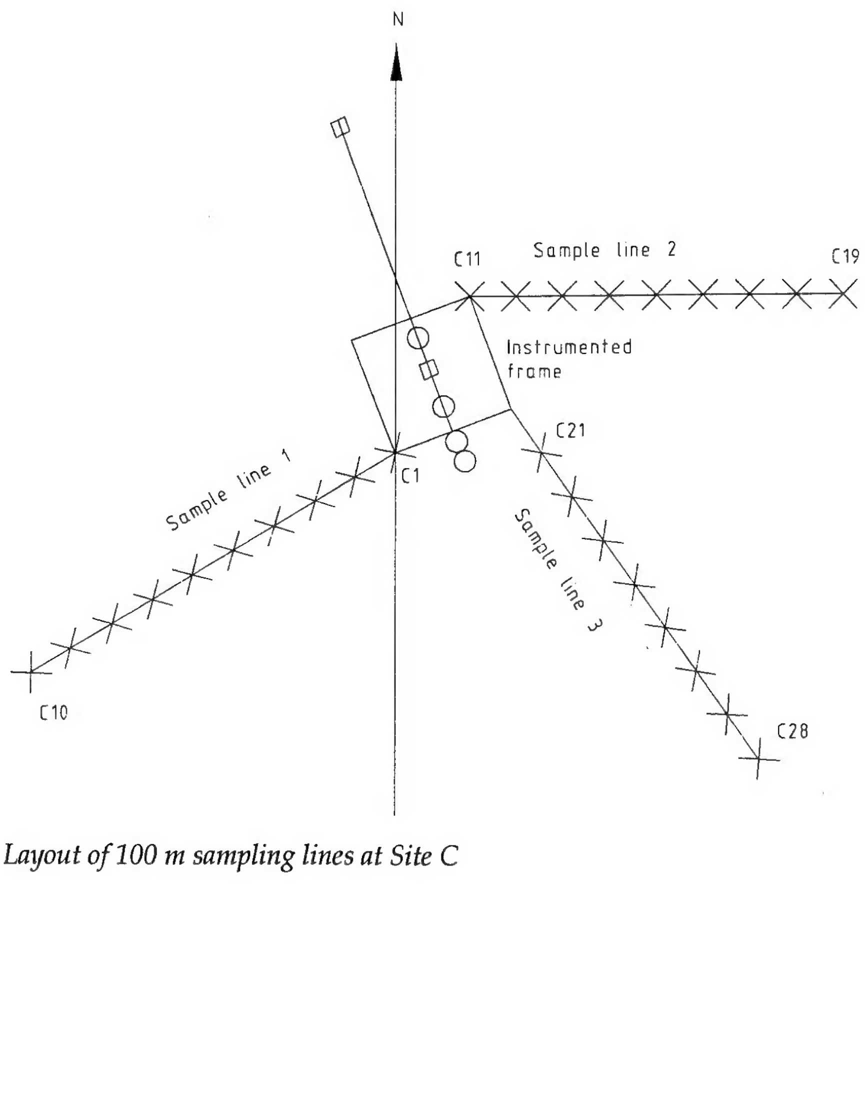

Figure 2. Layout of 100 m sampling lines at Site C

Table 3. Ship drift stations with video camera in frame

Stn Name	Date	Start Time (local)	Start Position Latitude (S)	Longitude (E)	End Position Latitude (S)	Longitude (E)
L	7/10/93	09:55	20° 12.32'	118° 26.2'	20° 12.68'	118° 26.88'
K	7/10/93	11:30	20° 10.01'	118° 31.23'	20° 10.38'	118° 31.60'
C2	8/10/93	14:13	20° 12.35'	118° 26.80'	20° 12.40'	118° 26.94'
F	10/10/93	07:06	20° 01.38'	118° 30.08'	20° 01.04'	118° 30.13'
A	11/10/93	15:08	20° 12.29'	118° 29.45'	20° 12.47'	118° 29.87'
J	11/10/93	16:14	20° 09.94'	118° 26.89'	20° 10.05'	118° 27.39'
B	11/10/93	17:09	20° 07.36'	118° 29.88'	20° 07.30'	118° 30.31'

3. Results

In this section video footage of the sites at which detailed sediment property statistics were obtained are described first. Then the statistics are presented.

Descriptions of video footage from the other sites listed in Table 3 are presented in Appendix B. From these observations, much of the marine growth on the sea floor is likely to be entirely missed by normal sediment surveys with grabs or corers, because of its patchy distribution. However some of this growth may well be significant for MCM activities in that it may influence acoustic backscatter, as well as affect diver and remotely operated vehicle (ROV) operations.

3.1 Sediment Sampling Sites

Site C

Site C was a flat and sandy area with "razor-shells" (*Pinna* species - a bivalve; see Figure 3) scattered irregularly over the seabed. Their distribution was very irregular, varying from one or two per metre to large clumps one metre across. The shells were approximately 20 mm long, with the pointed end vertically downward into the sand and the broader end protruding out of the sand by approximately 7 mm. The shell material itself was quite thin and translucent. Most shells seen on video were open, i. e. alive. Thin, green, drifting weed was often caught on the shell edges, especially at spring tide when there was a lot of this weed in suspension. The three lines, laid out by the divers at site C for sampling purposes, were positioned along predetermined bearings, and samples taken, as near as possible at 10 m intervals. In the great majority of cases clumps of shell did not prevent sampling. The sand in between shells was free of marine growth. Most samples at site C had a sand content of over 80%, and a mud content of less than 4%. 27 samples were successfully obtained. (Observed ranges of

gravel, sand and mud percentages at the measurement sites are presented in Table 4). The sand fraction was medium to very coarse. Sediment properties presented for site C ignore the presence of the shells. Normal grab sampling would have given a very misleading impression of the sea floor at this location. An individual grab would produce sand, a clump of shells or a mixture of sand and mangled shells.

Table 4. Ranges of gravel, sand and mud percentages

Site (No. of samples)	Site C (27)	Site K (10)	Site D (10)	Site J(10)
Gravel%	4 to 23	5 to 14	2 to 12	5 to 13
Sand %	75 to 94	65 to 81	87 to 98	75 to 83
Mud%	1 to 3	12 to 21	0 to 3	5 to 18

Site K

Some video footage was obtained near site K, not at exactly the same locations as were sampled by the divers, but about 0.1 nautical miles away. From the video, the sea floor consisted of fine sediment with occasional pebbles, pieces of weed, and occasional examples of more erect marine growth. The divers on their 100 m sampling line reported that there was no shell or weed, and that there was a very fine layer of sediment immediately on the sea floor's surface, with less fine sediment below it. The sediment at site K varied between gravelly sand, sand and muddy sand. The sand content was 65% to 80% and the sand fraction was medium to fine.

Site J

Video footage was obtained within 0.6 nautical miles of where grab samples were obtained at site J and showed a sea floor which looked like muddy sand with a significant amount of shell. Marine growth was not common along most of the track. In some of the footage there appear to be algal mats which would bind the sediment together , to some extent. This video footage is probably representative of site J. Sediment from all grab samples, except one, taken on the 1.81 km long drift at site J, consisted of sand. The exception was a muddy sand. Mud content was 5% to 18%. Sand content was 75% to 83%, and the sand fraction was very coarse to coarse.

Site D

No video footage was obtained at Site D. All grab samples taken on the 0.48 km drift at this site consisted of sand. Sand content was 87% to 98%, and the sand fraction was a medium sand.

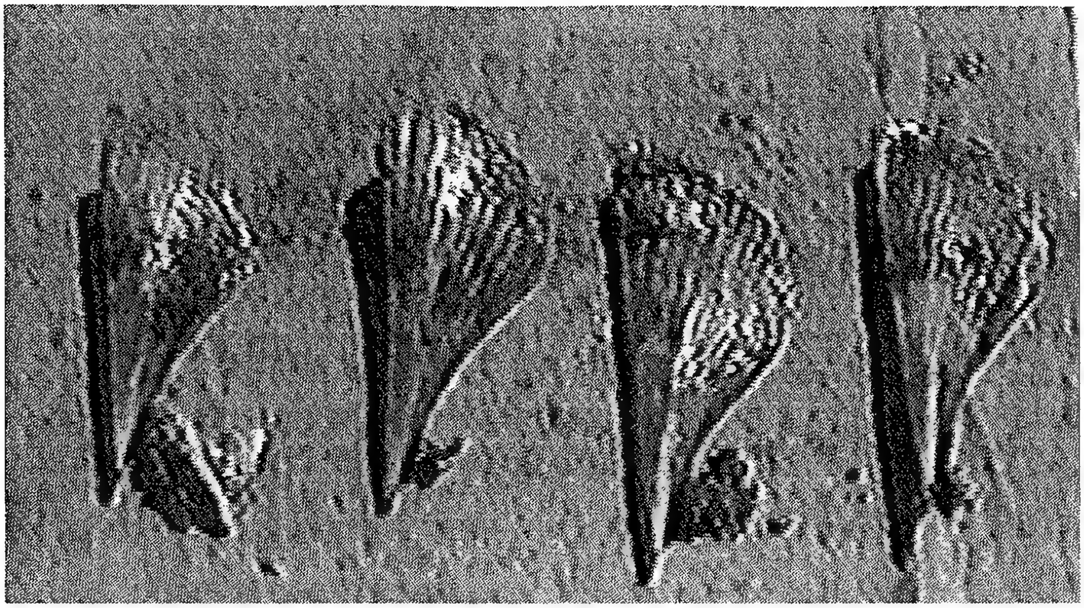

Figure 3. Pinna shells

3.2 Sediment property statistics

Statistics obtained for sediment grain density, bulk density and porosity are presented in Table 5. It can be seen that with ten samples an average grain density can be obtained to an accuracy of less than 1%, but individual readings can be different from the overall mean by up to 4%. For both bulk density and porosity averages over ten samples can be accurate within 2%, but individual samples can differ from the overall mean by up to 13%. Accuracy is here defined as standard error of the estimate of the mean value divided by the mean value, with standard error = (standard deviation)/$\sqrt{N}$, where N = number of sample values. Note that the 27 samples at C were obtained within 100 m of a central position. The 10 at K were obtained along a line 90 m long, those at D along a line 486 m long and those at J along a line 1806 m long. There is no clear trend for variability to increase as the length of the traverse, along which samples were taken, is increased.

Table 5. Sediment property statistics

Site (No. of samples)	Site C (27)	Site K (10)	Site D (7)	Site J(10)
Grain Density (kg/m^3)				
Average	2605.2	2453	2537	2550
Standard deviation, σ	32.4	60	20	20
$\sigma/\sqrt{N}$	6.2	19	8	6
Range	2510 to 2660	2390 to 2470	2520 to 2560	2520 to 2580
Bulk density (kg/m^3)				
Average	1872	1800	1670	1860
σ	95	50	80	100
$\sigma/\sqrt{N}$	18	20	30	30
Range	1621 to 1990	1745 to 1875	1573 to 1801	1643 to 1958
Porosity				
Average	0.41	0.48	0.51	0.43
σ	0.02	0.03	0.01	0.02
$\sigma/\sqrt{N}$	0.004	0.01	0.004	0.01
Range	0.378 to 0.451	0.446 to 0.537	0.489 to 0.527	0.411 to 0.474

($\sigma/\sqrt{N}$ is the standard error in the estimated value of the average value)

Variations in particle size statistics are presented in Table 6. It can be seen that point to point variations in Mz, in a region which would normally be classed as uniform by other criteria, are large. (Even over ten samples the standard error divided by the mean is 27% at site J). Individual Mz values can differ from the mean by up to 160%. Graphic standard deviation and graphic skewness values are also highly variable.

Table 6. Particle size statistics (in φ-units)

Site (No. of samples)	Site C (27)	Site K (10)	Site D (10)	Site J(10)
Mz				
Average	0.35	1.96	1.30	0.64
σ	0.18	0.24	0.23	0.55
$\sigma/\sqrt{N}$	0.035	0.08	0.07	0.17
Range	-0.11 to 0.64	1.58 to 2.28	0.92 to 1.63	0.05 to 1.67
σ_G				
Average	1.06	2.29	0.89	1.56
σ	0.10	0.36	0.20	0.66
$\sigma/\sqrt{N}$	0.19	0.11	0.06	0.21
Range	0.81 to 1.21	1.80 to 3.05	0.61 to 1.28	1.00 to 2.75
Sk_G				
Average	-0.0475	-0.18	-0.22	0.25
σ	0.05	0.15	0.12	0.25
$\sigma/\sqrt{N}$	0.01	0.05	0.04	0.08
Range	-0.16 to 0.06	-0.06 to -0.59	-0.38 to 0.02	-0.03 to 0.64

4. Discussion & Conclusions

4.1 Comparison with other results

Some of the results presented here can be compared with those of Richardson and Briggs (1993), who report variabilities in sediment properties within a single "sedimentary province" over distances of 1 km or less. Richardson and Briggs present the variability of their data only in terms of coefficients of variation (c. o. v.) from a large number of sites (15 in U. S. A. waters, 7 in Italian waters and 1 off northern Australia). Coefficient of variation (c. o. v.) is defined as:

C. o. v. = (Standard deviation)/(mean value).

Their ranges of c .o. v. values for porosity, Mz and bulk density are compared with those from this study in Table 7. Of particular interest are their values for sands and sand/shell. The c.o.v. values for porosity and Mz, found off Port Hedland, are similar to those for sands and sand/shell in Richardson and Briggs, but the c.o.v.'s for bulk density are higher off Port Hedland. This implies that the scatter in Mz values found off Port Hedland is typical. How to

meaningfully describe sea floor sediment sizes, in the light of these large variations is discussed below.

Table 7. Coefficients of variation (as a %) from Richardson & Briggs (R&B) and this study

	No. of sites	N/site	Porosity	Mz	Bulk density
R&B mud	7	7 to 141	1.6 to 13.0	0.8 to 11.8	1.5 to 6.3
R&B sand/mud	3	33 to 127	5.8 to 28.4	14.9 to 58.3	4.3 to 19.8
R&B sand	11	9 to 91	2.1 to 6.8	3.5 to 35.2	0.6 to 2.7
R&B sand/shell	1	118	7.8	81.6	2.6
R&B all sites	23	7 to 141	1.6 to 28.4	0.8 to 81.6	0.6 to 19.8
Site C	1	27	4.9	51.4	5.1
Site K	1	10	6.3	12.2	2.8
Site D	1	10	2.0	17.7	4.8
Site J	1	10	4.7	85.9	5.4

4.2 Sediment Grain Size Statistics

The size ranges for Mz, σ_G and Sk_G seen in Table 6 are so wide that one of the broader methods of defining grain size distributions needs to be used in practical applications. It can be seen that an individual sample at any site can easily have an Mz value 0.3 to 0.4 φ-units different from the overall average value, and hence there is little point in defining particle size to better than the nearest 0.5 φ - units. Similarly specifying σ_G or Sk_G to better than 0.5 φ - units is not warranted. (0.5 φ - units is equivalent to a factor of $\sqrt{2}$). In practice, there is just too much variability in the sea floor. This means that the broad categories set out in Appendix A are as precise as one needs to be. In cases where acoustic backscatter or mine burial models are sensitive to grain size, a range of expectations needs to be forecast. Predicting single values for a given area would be misleading.

However most currently available acoustic backscatter and mine burial models are more sensitive to the natural variations and uncertainties in other variables than they are to grain size, and specifying the latter to the nearest integer φ - value would be perfectly adequate in most cases. This also means that survey methods, with, for example, acoustic sea floor classification systems, need only provide sediment grain size to this level of accuracy. It also means that, for MCM purposes, analysis and survey methods can be simpler, and hence cheaper, and that many existing data bases are already adequate.

4.3 Influence of Marine Growth

Marine growths of types found off Port Hedland may well effect some diver and ROV operations, e.g. tangling up divers' drag lines, and ROV umbilicals. (For details see Appendix B). They will also have some effect on high frequency backscatter, because of the corals' calcium carbonate skeletons, or even the sponges' calcareous or siliceous spicules. For example, the wave length of a 300 kHz sound wave, in water, is approximately 5 mm. Much of the marine growth encountered has thicknesses of this order or greater, so that, for organisms with hard parts, their acoustic cross-sections would be similar to their geometric ones. Mine hunting sonar may or may not see these as discrete scatterers, depending on the sonar footprint, but inferring acoustic backscatter from sediment grain size alone is likely to be inaccurate in situations where marine growth with calcareous or siliceous parts is common. In deeper waters, with lower light levels, marine growth will be less developed and so less important. However much of the waters around northern Australia are relatively shallow.

The effects of the *Pinna* shell beds on acoustic backscatter will be significant for high frequency sonar. To illustrate this, if a *Pinna* shell is idealised as a sheet of Calcium carbonate (Calcite) 0.5 mm thick, a 300 kHz sound wave normally incident on it would have a reflection coefficient of 65% (Brekhovskikh ,1960, pp 45 -47). That is these shells would be significant sources of sea floor reverberation.

5. Acknowledgments

Thanks are due to the personnel of CSIRO's FRV Southern Surveyor, the five members of the RAN's Clearance Diving Team 4, who accompanied us, and to Messrs J. Boyle and M. Savage of Maritime Operations Division, DSTO, who helped greatly on the research cruise. Mr. J. Boyle is thanked for carrying out the laboratory sediment analyses.

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Appendix A
Sediment Descriptors

Sediment Types vs φ and mm grain size ranges

Sediment Type	φ values	Size (mm)
Gravel	< -1.0	> 2.0
Very coarse sand	-1.0 to 0.0	1.0 to 2.0
Coarse sand	0.0 to 1.0	0.5 to 1.0
Medium sand	1.0 to 2.0	0.25 to 0.50
Fine sand	2.0 to 3.0	0125 to 0.25
Very fine sand	3.0 to 4.0	0.063 to 0.125
Mud	> 4.0	< 0.063

Here $\phi = -\log(\text{diameter in mm})/\log(2)$.

σ_G is used as a measure of how well sorted a sediment is (Folk, 1980), so:

σ_G Range	Description
< 0.35ϕ	very well sorted
0.35 - 0.50ϕ	well sorted
0.50 - 0.71ϕ	moderately well sorted
0.71 - 1.00ϕ	moderately sorted
1.0o - 2.00ϕ	poorly sorted
2.00 - 4.00ϕ	very poorly sorted
> 4.00ϕ	extremely poorly sorted

Sk_G is used as a measure of the skewness of a sediment grain size distribution, so (Folk, 1980):

Sk_G Range	Description
+1.00 to +0.30	strongly fine-skewed (st. f. sk)
+0.30 to +0.10	fine-skewed (f. sk)
+0.10 t0 -0.10	near-symmetrical (sym)
-0.10 to -0.30	coarse skewed (c. sk)
-0.30 to -1.00	strongly coarse-skewed (st. c. sk)

Appendix B
Video Footage from Ship Drifts

Video footage of the sea floor, obtained with the ship drifting on station, were described in section 3.1 for the start of Site K and for Site J. The total list of ship's drift video-stations are given in Table 3 and their positions shown on Figure 1. All were over relatively flat or gently sloping areas. They showed a wide variety of features.

Site L.

The footage along the track of site L was very striking. It showed vast beds of *Pinna* shells, along the whole track with much fine, green weed drifting with the current and caught in the shells. The areas clear of shells appeared to be sandy.

Site C2.

The footage at Site C2 on 8/10/93 was similar, but there were reasonably featureless areas of sand with shell debris and some patches of fine, green weed.

Site K.

The start of the footage at Site K has already been described, but at its shallower, southern end the bottom became more sandy and gravelly, and marine growth (corals, sponges, etc) became common.

Site F.

At site F the sea floor was sandy with some rippled areas (rippled areas were not often encountered on this cruise). Towards the end of the drift-track, as the sea floor became more pebbly and then totally pebbly, there were corals, sponges and other marine growths, approximately one metre apart, and some fine, green weed. Before the sea floor became too pebbly there occurred algal mats binding the sand together. Sea floor samples taken 1 to 2 km from site F found the sediment to be sand or gravelly sand.

Site A.

Site A had little marine growth and appeared to be sandy gravel along the whole track. Largish shell fragments were very common, and there were some small patches of fine green weed. Grab samples taken very close to site A came up with sand or gravelly sand. It appears the human eye overestimates the amount of gravel present.

Site B.

Little good footage was obtained at Site B but fine, green weed, and branching corals were encountered towards the end of the drift.

It is clear, from the above observations, that much of the marine growth on the sea floor is likely to be entirely missed by normal sediment surveys with grabs or corers, because of its patchy distribution. However some of this growth may well be significant for MCM activities in that it may influence acoustic backscatter, as well as affect diver and remotely operated vehicle (ROV) operations.

Appendix C
Seabed Features from 3.5 kHz Runs and Divers' Underwater Videos

C1. Introduction

A number of interesting seabed features were observed in the approaches to Port Hedland, using a 3.5 kHz sub-bottom profiler and diver-operated underwater video cameras. Because so little is known about this area, it was thought that these observations were worth recording. They include the presence of surface lenses of sand, sub-surface layers, and build up of sand on the sides of sharp reef-like features. Diver observations of some of the long, linear, underwater ridges off Port Hedland established them to be rocky and reef-like, and covered with plentiful marine growth. They had previously been thought to be sand bars.

C2. Methods

The 3.5 kHz sub-bottom profiler was a Raytheon system, consisting of a CESP - 111 correlation echo-sounder processor, a PTR - 105B transceiver, an LSR - 1807M line-scan recorder, and, for the tow-fish, a V-fin type 807 with four TR109 transducers. The tow-fish was towed at 4 to 5 knots. Pulse length used was 25 ms, in chirp mode. Although this system was designed for deep waters, it can give useful results over the continental shelf. The tracks along which the system was towed are presented in Table C1. The run commencing at 23:00 on 6 October was approximately down the shipping channel off Port Hedland, and unlike others off Port Hedland was not a straight line. Navigation was by GPS (non-differential).

Table C1. 3.5 kHz sub-bottom profiler runs

Start			Finish		
Date/Time	Lat.(S)	Long.(E)	Date/Time	Lat.(S)	Long.(E)
6 Oct / 17:00	20° 11.2'	118° 25.0'	6 Oct /22:00	19° 55.0'	118° 25.0'
6 Oct / 23:00	19° 57.6'	118° 27.0	7 Oct / 05:40	20° 14.2	118° 33.3'
7 Oct / 19:11	19° 55.5'	118° 33.0'	7 Oct / 23:00	20° 12.3'	118° 33.1'
8 Oct / 00:01	20° 13.6'	118° 31.0	8 Oct / 04:31	19° 55.0'	118° 31.0'
8 Oct / 05:00	19° 54.9'	118° 29.0'	8 Oct / 10:10	20° 13.3'	118° 29.0'
8 Oct / 10:45	20° 14.0'	118° 27.0'	8 Oct / 13:21	20° 04.8'	118° 27.0'
10 Oct / 09:31	20° 02.48'	118° 34.75'	10 Oct / 13:00	20° 02.48'	118° 20.09'

(Times are local)

A team of 5 divers from the RAN's Clearance Diving Team 4 assisted on the cruise and carried out video camera traverses across a number of topographic highs in the area, to help determine their nature. The list of such traverses is presented in Table C2.

Table C2. Video Camera Traverses By Diver

Stn Name	Date (local)	Time (S)	Latitude (E)	Longitude (° M)	Bearing of Line
E	7/10/93	15:30	20° 04.00'	118° 22.50'	320
H	7/10/93	16:45	20° 03.80'	118° 30.90'	340
M	10/10/93	08:40	20° 01.75'	118° 34.70'	150
N	11/10/93	13:00	20° 07.70'	118° 26.70'	150

The positions of these lines are shown on Figure C1

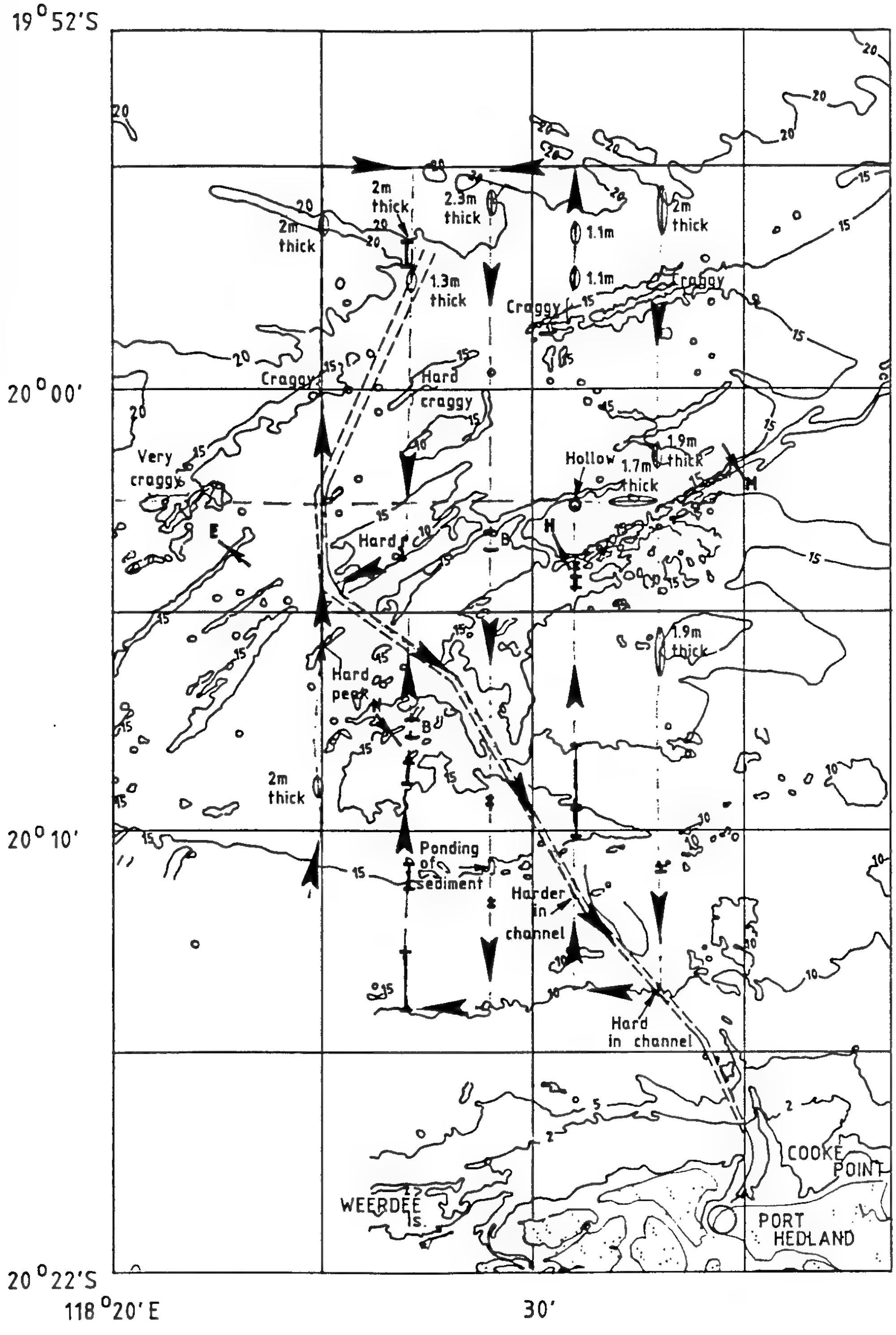

Figure C1. Map of approaches to Port Hedland, showing sub-bottom profiler tracks, positions of video-camera traverses, and seabed features of note :

0: surface lens; I: subsurface layers; O: hollow;

(B) : sediment build-up on side of a reef or ridge or bump; ↑ : video camera traverse.

C3. Results & Discussion

C3.1 Sub-bottom profiler results

Because the sea floor off Port Hedland largely consists of sand or gravelly sand (Mulhearn and Cerneaz, 1994), there is little acoustic penetration over most of the area. Positions of observed features are shown on Figure C1. From the strength of the echo, most ridges, bumps and other topographic highs, reaching to within 10 m of the sea surface, are significantly harder than their surroundings and are almost certainly rocky. They are usually quite rough, rather than smooth.

When surface lenses of sediment occur (See Figure C2(a) for an example) they are mostly near the 20 m depth contour, between 19° 55'S and 19° 57.5'S (6 cases). From previously obtained grab samples nearby, in depths greater than 20m, (Mulhearn and Cerneaz, 1994) the underlying sediment appears to be sand with very little mud or gravel. No nearby bottom samples are available in the shallower areas. Other surface lenses occur near or across slight bathymetric highs along 188° 32.5'S (3 cases). One case occurs near 20° 09'S, 118° 25'E, and another on the side of the shipping channel (due to dredging, perhaps). That the sound can penetrate in these places and return a discernible reflection, suggests that the near-surface sand in these places is less well packed than elsewhere, possibly shifting back and forth under tidal action. These lenses had thicknesses estimated at 1 to 2 m.

Subsurface layers are visible in the sub-bottom profiler records mainly around the 15 m contour enclosing a slightly deeper area near 20° 10'S (9 cases), which previous surveys have shown to be an area of muddy sand. (See Figure C2(b) for examples). A subsurface layer was also found south of this region along118° 27'E, another below a surface lens at 19° 57'S, 118° 27'E, and two more, south of a reef, near 20° 04'S, 118° 31'E.

Areas of sediment build-up, possibly caused by tidal currents, were apparent on the sides of a few hard bathymetric highs - on the east of a reef at 20° 2.5'S, 118° 22.5'E, and on the south of reefs at 20° 03.3'S, 118° 29'E, and 20° 07.5'S, 118° 27.0'E. A hollow, perhaps due to scouring, was seen near 20° 02.5'S, 118° 31.0'E. At any one location ebb and flood tidal streams are often of unequal strength. This is especially likely close to topographic features, where an area near an obstruction may be in its wake for one half of a tidal cycle, but exposed to the full current in the next half cycle. There can then easily be a build up or a scouring away of sea floor sediments in such places.

C3.2 Video camera traverses of some bathymetric features

Off Port Hedland, between 19° 57'S and 20° 09'S, there are a number of long, linear features tending approximately NNE to ESE. Harris et al. (1991) postulated that similar features off Broome and Port Walcott were sand dunes. Off Port Hedland, traverses by divers, equipped with video cameras, across these features, at stations E and M (See Figure C1. and Table C2) showed that these were rocky features, with a fair covering of

marine growth, including corals and sponges. In addition large quantities of large, fleshy, algae were present at M, where the marine growth was quite luxuriant. The traverse at station H was away from the reef, on its north side, and showed an extensive area of very coarse gravel - stones not shells, and patches of fine green weed were also common. The traverse at station M showed similar features on the reef's north side, in places. The traverse at station N was across a shorter ridge with a different orientation, but it also was a rocky reef, with marine growth, (e. g. corals and algae) though the growth was less dense than at M.

Given that the long linear features off Port Hedland are not sand bars but rocky reefs, it is likely that the even more common linear features off Broome and Port Walcott are also rocky reefs. This greatly changes perceptions of likely mine burial mechanisms in these areas.

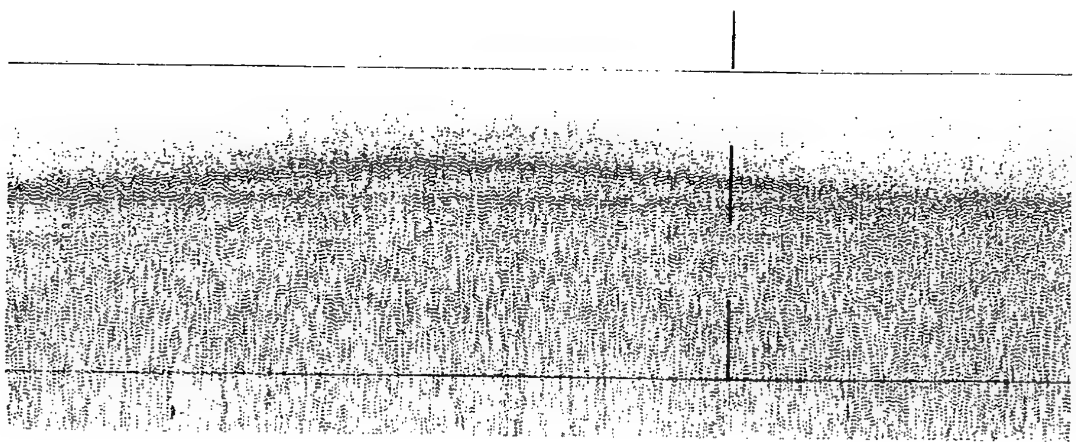

Figure C2 (a). Example from sub-bottom profiler records of a surface lens, near 19° 56.5'S, 118° 25'E. Thin horizontal lines are 0.025 s apart. (Assuming a sound speed of 1700 m/s in sand this corresponds to a depth of 21.25 m).

Figure C2 (b). Example from sub-bottom profiler records of subsurface layers near 20° 08.5', 118° 31.0'E.

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P.J. Mulhearn

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19. ABSTRACT

The spatial variability of seabed sediment properties over short ranges is investigated, and it is found that, at least for sands, sediment grain-size varies within a factor of $\sqrt{2}$ over distances of order 100 m. Evidence is then presented that this sediment variability, found off Port Hedland, is similar to that at many other locations around the world. Hence for acoustic backscatter and mine burial models the conventional categories: very coarse, coarse, medium, fine and very fine, for sands are as precise as it is practical to be. This implies that survey methods, with, for example, acoustic sea floor classification systems, need only provide sediment grain size to this level of accuracy. It also means that, for mine-counter measures purposes, conventional survey methods can be relatively simple, and that many existing data bases are quite adequate.

From underwater video footage it is clear that many important seabed features, such as shell beds, branching corals and seaweed clumps, can easily be overlooked in sea floor surveys, with either grabs or corers alone, and that this, at times, would lead to misleading conclusions concerning environmental factors relevant to mine warfare operations.

A number of interesting seabed features have been observed near Port Hedland using a sub-bottom profiler and diver-operated underwater video cameras. Because so little is known in this area, it was thought these observations were worth recording, as an appendix to this report. In particular video-camera observations of some of the long, linear, underwater ridges off Port Hedland established them to be rocky reefs, rather than sand bars, as was previously thought. This changes previous perceptions of likely mine burial mechanisms off a number of Northwest Shelf ports.